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# THEORIES OF TURBULENT COMBUSTION IN HIGH SPEED FLOWS

AFOSR Grant No. 89-0539A

Final Technical Report for Period  
1st September, 1992 - 31st August, 1993

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## Objectives of Research

The aim of this research was to improve understanding of turbulent combustion in high speed flows. Particular attention was directed to phenomena which make this type of combustion different from combustion in low speed flows. Finite chemical reaction rate effects, and interactions between density inhomogeneities and mean force fields arising from gradients of mean pressure and Reynolds shear stresses, were identified as phenomena which may become particularly important in high speed flows.

The research was part of a collaborative program with Professors P. A. Libby and F. A. Williams of the University of California, San Diego. The aspect of this joint research activity which was carried out in Cambridge was the development of a presumed pdf model of high speed turbulent combustion in a shear layer. This model was used to explore the influence of reaction rate mechanisms and transport processes on predicted flame properties. Laminar flamelet properties from UCSD were incorporated.

## Summary of Research

A theoretical model was developed<sup>(1,2,5)</sup> of nonpremixed turbulent combustion in high speed flows. The turbulent flow was described using an algebraic stress model as an approximation to a full second moment formulation. Terms in the resulting transport equations which describe interactions between flow and heat release were carefully considered.

Three terms in the transport equation for a Reynolds stress component were studied in detail. These terms, representing processes of dilatation dissipation, pressure dilatation and pressure strain correlation, provide mechanisms through which interactions can occur between high speed flow and heat release. New theoretical models for these processes were developed and tested.

Heat release rates were calculated in two alternative ways: either from a conventional presumed pdf flame sheet model or from a new laminar flamelet model<sup>(2,5)</sup>. In the flamelet model it was found essential to include effects of flame stretch and also of enthalpy changes due to high speed flow.

Model predictions were compared with published experimental data (Evans, J. S., Schexnayder, C. J. Jr. and Beach, H. L. Jr., NASA TP 1169, 1978). It should be noted that these supersonic combustion experiments involve relatively low Mach numbers.

Conclusions are as follows. For the  $H_2$ -air nonpremixed turbulent combustion experiment conducted by Evans et al. in a high-speed shear flow, the flamesheet model can reasonably predict the combustion region but fails to predict the profiles of mass fractions, especially for  $H_2$  near the jet axis and  $O_2$  close to the jet edge. The inclusion of both dilatation dissipation and pressure dilatation leads to no significant improvement of the simulation results in this relatively low Mach number test case. The results predicted by the laminar flamelet model dramatically improve the profiles of species mass fractions. This indicates that the high turbulent strain rate usually observed in high-speed flow has a significant influence on the turbulent combustion. The widely used assumptions, such as fast chemical reaction rate, and unity Prandtl and Lewis numbers, are not suitable for this high-speed turbulent flow. It is necessary to include effects of kinetic energy changes in the calculations. Numerical results also show that this supersonic nonpremixed turbulent combustion flow satisfies the criteria of the laminar flamelet model.

### Personnel

Professor K.N.C. Bray : principal investigator.

Dr. L.L. Zheng : research worker.

### Publications

1. L. L. Zheng and K. N. C. Bray: Effects of dilatation dissipation on turbulent shear layer combustion in high speed flow. 24th Symp. (Int.) on Combustion, The Combustion Institute, pp. 405-411, 1992.
2. L. L. Zheng, Doctoral thesis, University of Cambridge, 1993.
3. L. L. Zheng and A. M. Savill. Accounting for non-local diffusion effects in combustion of a supersonic co-flowing jet. Proc. Joint Meeting of British and German Sections, The Combustion Institute, 1993.
4. K. N. C. Bray, Paul A. Libby and Forman A. Williams: High Speed Turbulent Combustion, in Turbulent Reacting Flows, (Eds. P. A. Libby and F. A. Williams), Academic Press, 1994.
5. L. L. Zheng and K. N. C. Bray. The application of new combustion and turbulence models to  $H_2$ -air nonpremixed supersonic combustion. Combustion and Flame 99, 440-448 (1994).

### Interactions

Close collaboration was maintained with Professors Paul A. Libby and Forman A. Williams of the University of California, San Diego. Laminar flamelet properties calculated at UCSD were incorporated in the calculations. A review article was published<sup>(4)</sup>.

### Inventions

None.

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